HST - WFPC2 PHOTOMETRY OF THE GLOBULAR CLUSTER NGC 288: BINARY SYSTEMS, BLUE STRAGGLERS AND VERY BLUE STARS

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Abstract. We report on new WFPC2 observations of the globular cluster NGC 288, focusing our attention on peculiar stars. A very pronounced binary sequence, paralleling the ordinary Main Sequence (MS) is clearly observed in the Color Magnitude Diagram (CMD) and a huge relative fraction of Blue Straggler Stars is measured. The dataset offers the opportunity of studying the evolution of a large population of binaries (and binary evolution by-products) in a low density environment, where the evolution of such systems is not dominated by collisions and encounters. Three (very) Extreme Horizontal Branch Stars have been found, all lying outside of the cluster core.

1. Introduction

As a part of a long term programme aimed to obtain complete samples of all the evolved stars in a few prototypical globular clusters[1], we have obtained multi-wavelenght observations of a couple of WFPC2 fields towards two very important globulars: NGC 2808 and NGC 288.

Here we report some preliminary result about NGC 288, a cluster that holds a key role in the literature about the *Second Parameter* phenomenon (see [1] for a review, and references therein).

[1]The programme is named *Large Population Studies of Globular Clusters (LPSGC)* and is a collaboration between scientists from the Bologna and Rome observatories, the Goddard Space Flight Center (Baltimore, MD) and the University of Virginia (Charlottsville), see Ferraro, this volume.

2. Observations and data reductions

We observed a field centered on the core of the cluster (Central Field, hereafter CF) with the filters F255, F336, F555, F814 and a field a couple of arcmin apart (Outer Field, hereafter OF) with the filters F555 and F814. Because of a problem in the pointing the two fields have a small overlapping area and the OF observations saturates ~ 0.5 *mag* above the Horizontal Branch (HB) level.

The data reduction has been performed with DOPHOT [2], according to the general prescriptions adopted by [3]. The absolute calibration in the Johnson-Cousins system has been obtained adopting the Holtzman relations [4]. The final magnitudes are the average of various (2-4) measures on repeated exposures.

3. The CMD: a clear secondary sequence

In fig. 1 the V *vs.* V-I CMD of the whole sample and the V *vs.* U-V CMD of CF are shown. The most striking feature of these diagrams is the evident secondary sequence paralleling the Main Sequence that is naturally associated with a population of couples of MS stars measured as a single source. This occurrence can be due to chance superposition of otherwise unrelated stars or to the physical association of the couple (i.e. binary systems, see [5] for a review).

To evaluate the number of chance blending contaminating the observed secondary sequence and to obtain robust estimates of the true binary fraction, extensive artificial stars experiments are needed [6] and are presently in progress. However we are dealing with a very low density and relatively nearby cluster, so crowding has not to be a major concern in this case. The probability that two stars images overlap to within 2 FWHM is $P_{overlap} = \pi * FWHM^2 * N_s/A$, where N_s is the number of stars in the observed field and A is the area of the field. For our Central Field, the most "crowded" one, $P_{overlap} < 3\%$, thus the contamination by chance blending is expected to be negligible. So, it can be safely expected that most of the stars populating the secondary sequence are genuine binary systems and that the binary fraction in this cluster is remarkably high.

4. Blue Stragglers: a very high fraction

It is now widely accepted that Blue Straggler Stars (BBS) are products of the evolution of binary systems [7]. If the above discussed secondary sequence is indeed due to a large binary fraction in NGC 288, a significant population of BSS is also expected. This is actually the case. In fig. 2 the BSS are clearly identified in the F255 *vs.* F255-U CMD. While the absolute

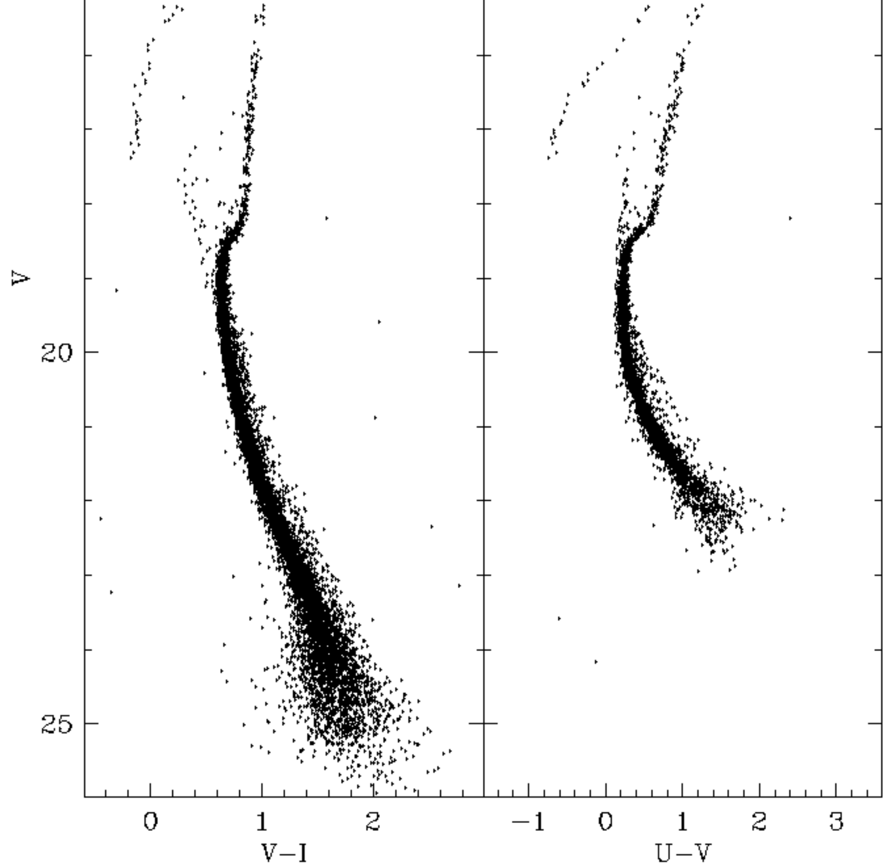

Figure 1. (V-I,V) and (U-V,V) Color magnitude diagrams of NGC 288.

number of BSS is not particularly remarkable (as expected for such a low mass cluster), the specific frequency - defined by [8] as the ratio of the number of BSS and the number of HB stars - is one of the highest ever found in a globular, $F_{HB}^{BSS} = 1.35$. In table 1 [2] the F_{HB}^{BSS} ratio is reported together with other relevant parameters for a handful of clusters observed with HST-WFPC2 and with the adoption of the same selection criteria for the BSS sample (see [9]). The sample is very small but homogeneous and fully self-consistent for what concern the census of BSS.

It is immediately evident that the only cluster with a comparable F_{HB}^{BSS} ratio is M80 which is a very dense cluster and that harbours most of its BSS in the very central regions. In particular the two entries for F_{HB}^{BSS} refer to the global and the central value respectively. [9] argues that the exceptional (and exceptionally concentrated) BSS population in M80 can be understood if it is assumed that the cluster is in a very special phase of its dynamical evolution, i.e. it is struggling against the unavoidable core collapse, a favorable condition for the formation of *collisional* BSS. However, while the collision time (see [10], eq. 8–125) for a MS star in the core of M80 is $t_{coll}(M80) \sim 5\ Gyr$, $t_{coll}(NGC288) \sim 1000\ Gyr$, so collisions between MS stars has to be exceedingly rare. Thus, it is very likely that the large

[2]First three columns from [12], last column from [9] and the present work.

TABLE 1. Comparison between the F_{HB}^{BSS} and other relevant parameters for an homogeneous selected sample of Globular Clusters. The clusters are ordered with growing central density.

ID	[Fe/H]	$\log\rho_{0\,L_{\odot V}pc^{-3}}$	$t_{rc[10^9 yr]}$	F_{HB}^{BSS}
NGC 288	-1.40	1.80	1.230	1.35
NGC 6205 - M13	-1.65	3.32	0.871	0.17
NGC 5272 - M3	-1.66	3.54	0.602	0.67
NGC 6341 - M92	-2.24	4.38	0.069	0.55
NGC 6093 - M80	-1.64	4.79	0.040	1 - 1.7
NGC 7099 - M30	-2.13	5.07	0.002	0.49

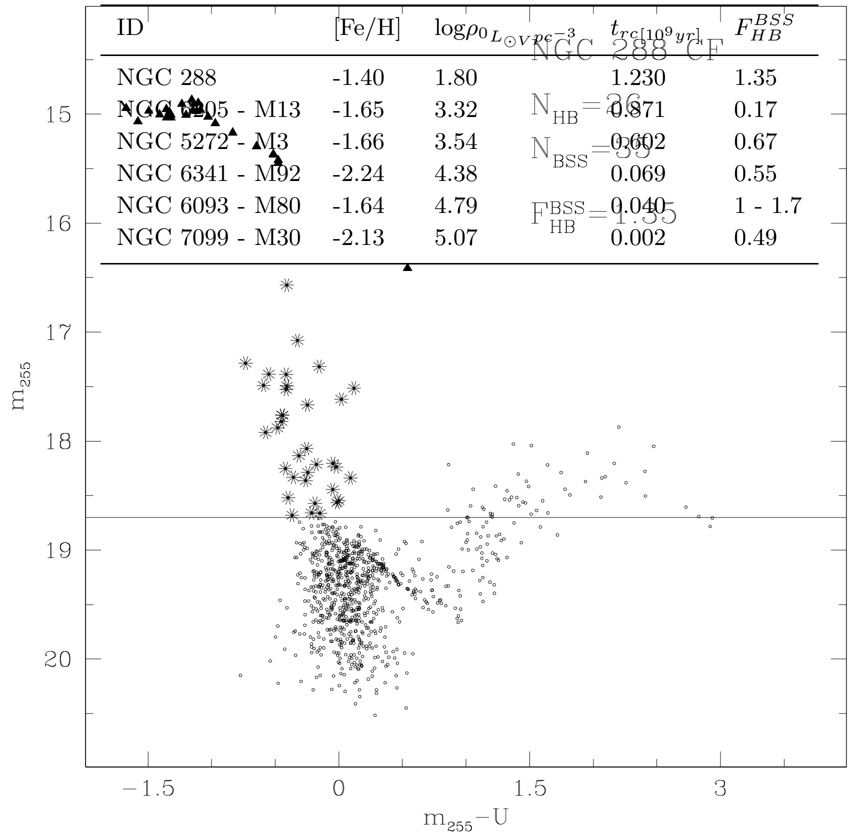

Figure 2. F_{HB}^{BSS} ratio from the selection operated in the F255W *vs.* F255W-U plane, according to the method adopted by Ferraro et al. (1999). BSS are indicated by asterisks and HB stars by triangles. The faint limit for BSS selection is indicated by the $m_{255} = 18.8$ line.

majority of BSS in NGC 288 originated from a population of *primordial binaries* through a mechanism as efficient as the one operating in M80, but completely different.

5. HB morphology: Extreme Horizontal Branch stars?

In the right panel of fig. 3, a zoomed view of the HB stars in the (V, V-I) CMD is reported, while the left panel report the position of the same stars

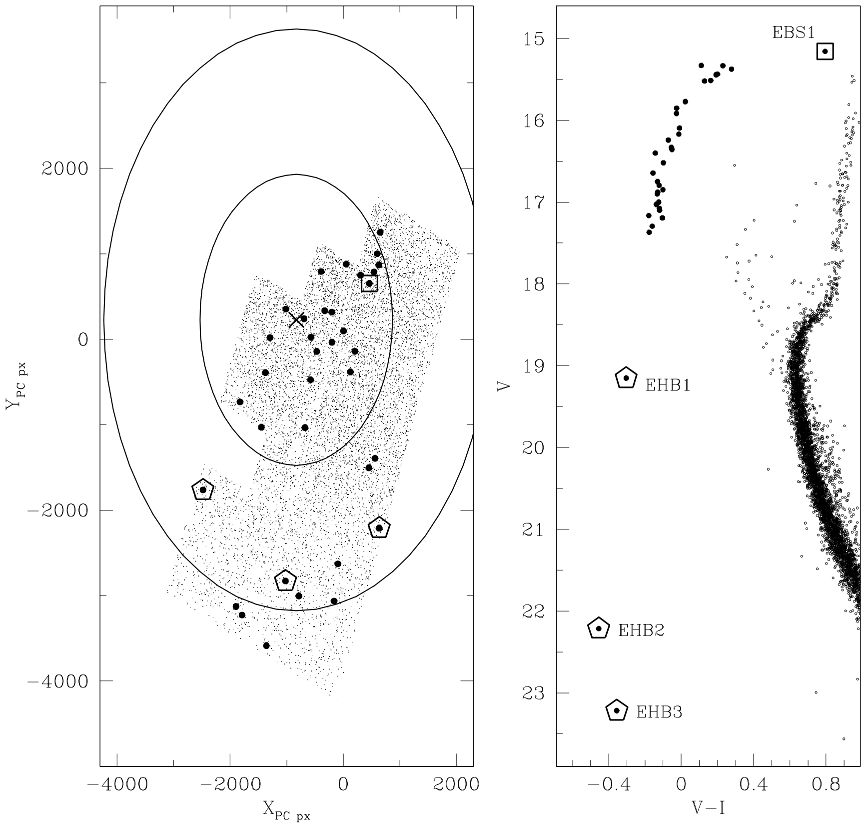

Figure 3. **Right panel:** HB morphology for the CF+OF sample. HB stars are indicated by larger dots, the candidate Evolved BSS by the open square and the candidates EHB stars by pentagons.**Left panel:** Map of the whole sample. North is up and East is Left, the symbols are the same as in the right panel. The cross marks the center of the cluster. The circles with radius of 1 r_c and 2 r_c are also reported.

within the whole observed field. Three main facts can be remarked about the HB morphology:

– The overall HB morphology is the well known - almost purely blue - one of NGC 288. There is no possible candidate RR Lyrae star and a marginally significant gap around $V - I = 0.05$.
– There is a single red HB star. Since the red clump is the place where the Evolved BSS (EBSS, [11]) are expected to lie, during their core He burning phase, may be that this anomalous HB star is indeed an EBSS. Based on crude evolutionary time consideration one would expect $N_{EBSS} \sim 0.6 * N_{BSS}$. In the present case $N_{EBSS} \sim 2$ is expected, in good agreement with the observed sole red HB star. Note that the EBSS candidate is found near the center of the cluster (fig. 3, left panel).
– There are three very blue stars on the ideal extension of the HB ridge line, much fainter than the end of the main HB distribution. All of these Extreme HB (EHB) candidates are genuine, isolated stars that have many consistent measurement in each filter from repeated exposures. All of them lie well beyond the cluster core, far from the densest region

of the cluster. Unfortunately we have only V and I observations for these stars since they all fall in the OF. While EHB1 is fully compatible with being a bona-fide HB star, the nature of EHB2 and EHB3 is much more uncertain. It may be that no reasonable HB model would be able to push stars at such high temperatures. Tests in this sense are in progress and other hypothesis are under consideration. Preliminary checks seems to exclude background quasars, field stars, white dwarfs and ordinary cataclysmic variables as viable possibilities.

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